Powering Lower Limb Prosthetics with Muscle-like Actuators

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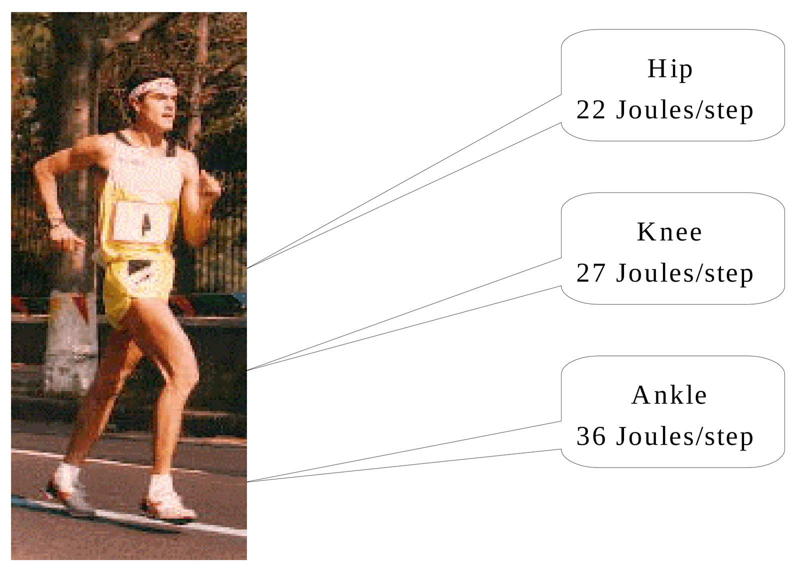
Introduction

Kinematic and kinetic analysis of walking speed gait reveals the intact ankle supplies a significant amount of energy during stance phase plantar-flexion which is unavailable to the amputee.



Gitter, Czerniecki, and DeGroot, 1991

The objective of the Powered Prosthetic Project is to improve below-knee amputee gait by using a powered prosthetic limb to supply the missing energy.

Specific Aims

Our overall aim is to build and test a powered, below -knee prosthetic limb for use by an active, ambulatory amputee. To measure our success in this endeavor, we have formulated three hypotheses:

Hypothesis 1 : A powered prosthetic limb will reduce the metabolic cost of amputee locomotion.

Hypothesis 2 : A powered prosthetic limb will improve the symmetry of amputee gait as quantified by kinematic and kinetic analysis (video and force measurements).

Hypothesis 3 : A powered prosthetic limb will reduce the perceived level of effort required for amputee locomotion.

Methods

Design and development of the powered, below-knee prosthetic limb includes several identified tasks:

- Identify prosthetic limb performance requirements.
- Develop a lightweight, musculotendon-like actuator complete with Hill-like damping.
- Design and fabricate prosthetic limb.
- Specify and tune control system.
- Conduct bench-top performance tests simulating gait.
- Conduct tests with human subjects in VA gait lab.

Powered Prosthetic Requirements

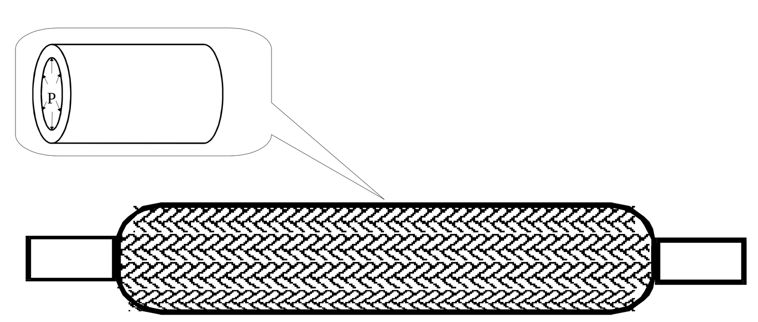
- 8 hour operation.
- Light-weight with high power output.
- Minimal maintenance.
- Quiet!
- High user satisfaction.

Lower Limb Design Requirements

- Plantar-flexion torque of 110 Nm.*
- Calcaneous moment arm of ~47 mm.
- Ankle range of motion of 30 degrees.
- Ankle angular velocity of 225 degrees/second.
- Tendon energy storage of 16 J.

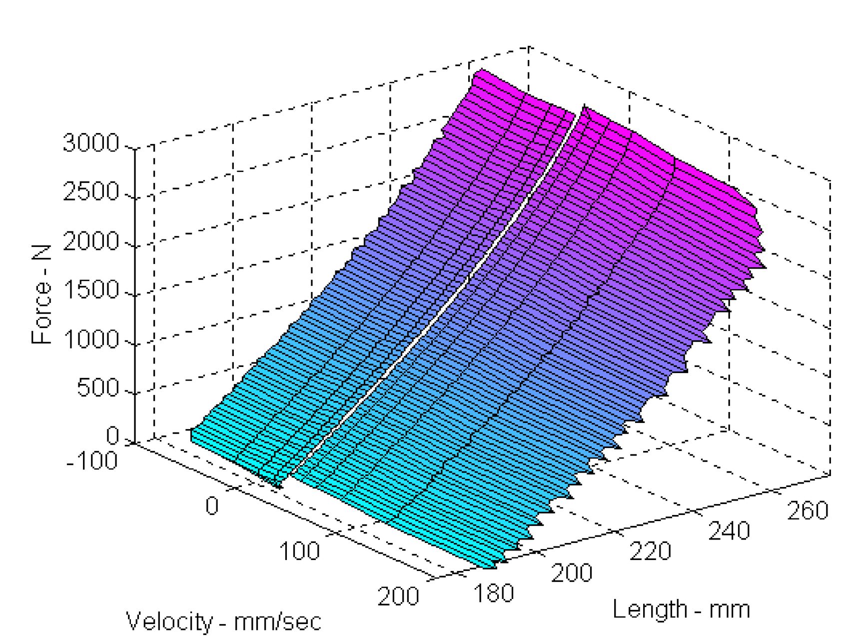
McKibben Actuator

The McKibben actuator is made from an inflatable inner bladder sheathed with a double helical weave which shortens lengthwise when expanded radially. While it requires an external pressure source, its high force-to-weight ratio makes it ideal for mobile robot and prosthetic applications.



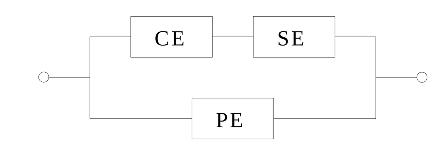
Current Actuator Performance

The force generated by a McKibben actuator is a function of activation pressure and length. In comparison, the force generated by biological muscle is a function of neural activation, length, and velocity.



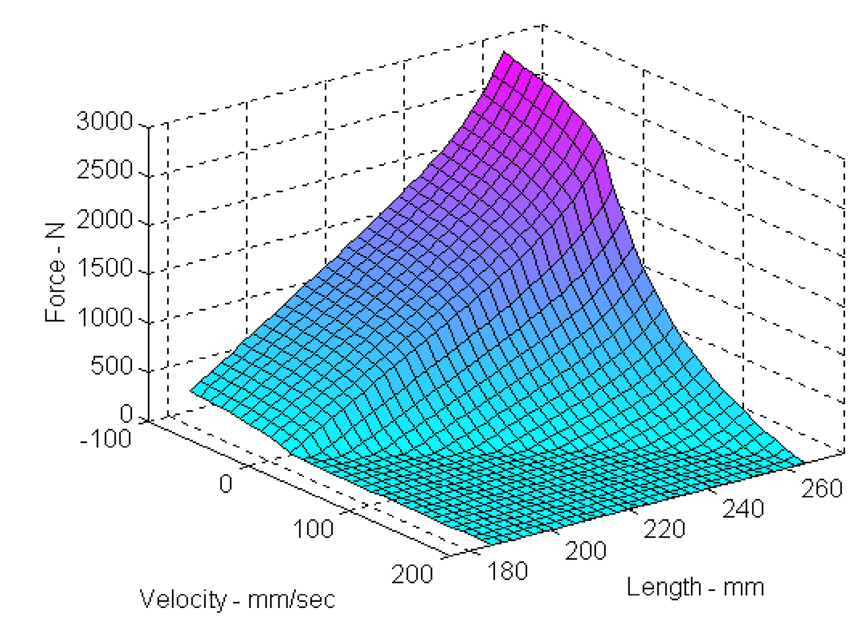
Hill Muscle Model

To capture the relevant properties of biological muscle for this application, we chose to use Hill's muscle model for simulating the gastrocnemius and soleus muscles.



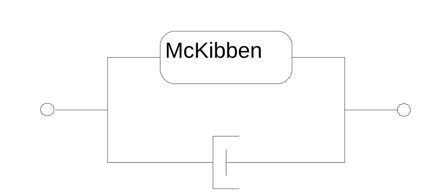
Desired Actuator Performance

Using Hill's muscle model scaled for the human gastrocnemius and soleus, the desired force-length-velocity profile is given by:



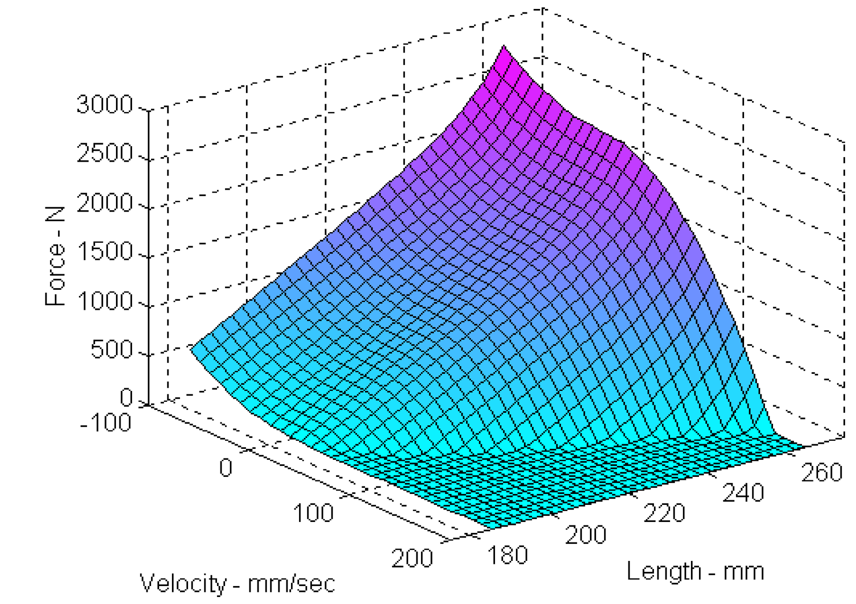
McKibben Artificial Muscle Design

With a small, hydraulic cylinder placed in parallel with the McKibben actuator, the contractile element can be modeled by:



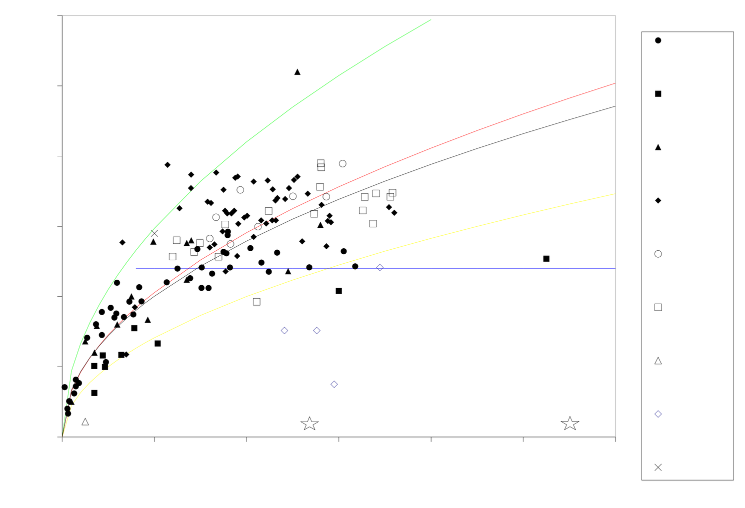
Expected Performance

Hydrodynamic simulation including an empirical model of the McKibben actuator predicts the expected performance:



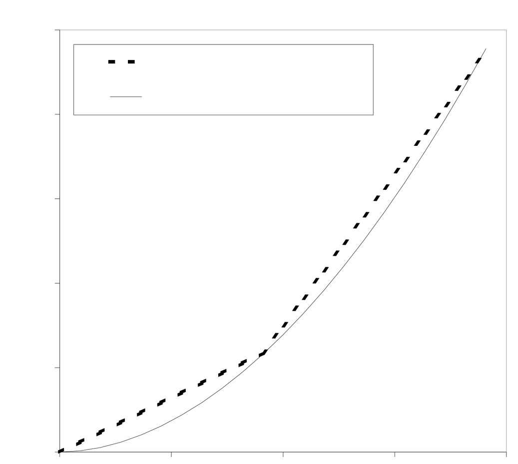
Tendon Design

The Achilles tendon stores a significant amount of energy during the early part of stance phase, then returns this energy during the latter part. We have developed an Energy Storing Tendon (EST) model based on published studies of human and animal locomotion. The slope of the stress-strain curve (i.e. the tangent modulus) is the primary model feature:



Expected Tendon Performance

Using a two spring implementation of the Energy Storing Tendon model, our predicted "tendon" performance is:



Conclusions

We have designed and are constructing a light-weight, musculotendon-like actuator to meet identified prosthetic limb performance requirements. Following bench-top tests, we plan to use this actuator to develop a powered prosthesis which we hope will reduce metabolic costs, improve gait symmetry, and lower levels of perceived exertion during amputee locomotion.

Further Information : http://rcs.ee.washington.edu/BRL

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